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SYNOPSIS OF 1991 RESEARCH ON DEVELOPMENT OF THE FUNGUS *Beauveria bassiana* FOR GRASSHOPPER CONTROL IN AFRICA

Project Title: Biological Control of Grasshoppers and Other Crop Pests in Cape Verde

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EXECUTIVE SUMMARY

This report summarizes the results of research in 1991 to develop the fungus *Beauveria bassiana* for grasshopper and locust control in Africa. Funding for this research was provided by the U.S. Agency for International Development, Bureau for Africa, through a cooperative project entitled "Biological Control of Grasshoppers and Other Pests in Cape Verde," involving Montana State University (MSU), the Instituto Nacional de Investigacao Agraria (INIA) in Cape Verde, and Mycotech, a research and development firm in Butte, Montana. Lab and field research with *B. bassiana* against grasshoppers in Cape Verde was initiated in 1990. First-year results were promising, with around 100% mortality in lab bioassays and 90% mortality in field cage trials. However, small (1 hectare plot) field trials revealed difficulties in formulation and coverage. Following strain and formulation improvements, field trials against grasshoppers in the United States and Canada in late spring/early summer 1991 achieved excellent results, suggesting that the previous year's problems had been overcome.

Major objectives of the 1991 research program in Cape Verde were to evaluate new formulations in Africa, to adapt formulations to application equipment commonly used in Africa, to assess storage and field stability under African conditions, and to further evaluate the efficacy of *B. bassiana* against African grasshoppers, principally *Oedaleus senegalensis*--one of the most economically damaging species in Africa. Results from this 1991 research program were highly successful. Field trials were conducted using 4 different formulations applied with two different types of hand-held application equipment. The most successful formulations (wheat bran bait and an oil formulation with emulsifier) achieved 98% mortality in 7 days. Results with a wettable powder (clay) formulation were nearly as successful. These are by far the best results that have yet been obtained in field trials with natural entomopathogens against grasshoppers in Africa. Mortality levels compare favorably with those achieved with chemical pesticides, without any environmental and public health risks. Stability studies showed that formulations were very stable under typical storage and distribution conditions in Africa. Field results demonstrated that spores on sprayed vegetation were an important source of infection and that formulations provided sufficient protection to maintain an infective level for at least 3 days, despite exposure to tropical sunlight, heat, and humidity. The 1991 results in Cape Verde warrant follow-on research to further develop and operationalize the use of *B. bassiana* for grasshopper and locust control in Africa.

TABLE OF CONTENTS

	Page
Executive Summary	i
Introduction	1
Host Range and Strain Improvement	2
Spore Production	3
Formulation	3
Stability Studies	5
Laboratory Bioassays	8
Cage Trials	9
Field Trials	13
Conclusions	16
References	18

INTRODUCTION

This report provides a synopsis of research in 1991 to develop the fungus *Beauveria bassiana* for grasshopper and locust control in Africa. Work was conducted by the Instituto Nacional de Investigacao Agraria (INIA) in Cape Verde and Mycotech Corporation, Butte, Montana, as part of the Montana State University-INIA project, "Biological Control of Grasshoppers and Other Pests in Cape Verde." This project was funded by the United States Agency for International Development, Bureau for Africa, under Cooperative Agreement AFR-0517-A-00-9064-00.

B. bassiana is a common, naturally occurring pathogen of insects. Conidia (spores) of the fungus attack insects by adhering to the insect cuticle, germinating, and penetrating the cuticle. The fungus then replicates in the insect hemocoel, killing the insect in 3 to 10 days. Under conditions of high humidity, *B. bassiana* may sporulate on the dead insect. However, high humidity is not necessary for the initial infection.

B. bassiana has several advantages that allow it to be developed as an effective biological insecticide: (1) Infection is rapid, causing reduced mobility and feeding in grasshopper populations within 48 hours, with mass mortalities beginning soon thereafter. (2) Infection does not depend on specific weather conditions, making *B. bassiana* effective as a bio-insecticide in a wide range of environments. (3) Insects can be infected both by direct contact with spores and through secondary contact with spores sprayed on vegetation. (4) Spores can be efficiently produced *in vitro* using inexpensive, readily available nutrients. As a result, large-scale, low-cost production is economically feasible. (5) Spores are stable and can be mixed with a wide range of liquid or solid carriers and applied using conventional insecticide application equipment. (6) *B. bassiana* does not affect living organisms other than insects and therefore poses minimal environmental or human health risks. Furthermore, specific strains of this fungus only affect certain insects, allowing bio-insecticides to be developed for specific insect pests.

Mycotech first isolated a *B. bassiana* strain virulent to grasshoppers in 1987. Since then, it has been developing production, formulation, and application techniques for *B. bassiana* for grasshopper control. Mycotech and INIA personnel initiated research with this fungus in Cape Verde in 1990 under the Montana State University-INIA biocontrol project funded by the Africa Bureau. Laboratory tests at INIA against one of the most economically damaging West African grasshopper species, *Oedaleus senegalensis*, began in early 1990. The first field trials in Cape Verde were conducted in August of that year. Both lab and field results were promising. Grasshopper mortalities in lab bioassays consistently approached 100%, with 90% mortality in field cages using wheat-bran bait containing spores. However, open field trials using liquid sprays on small 1 hectare plots achieved only around

30% mortality owing to grasshopper migration and formulation problems that resulted in poor coverage. Following improvements in formulation, new field trials were conducted in the United States and Canada during May and June 1991. These trials achieved excellent results with both aerial spraying of liquid formulations and ground spreading of bran bait.

Major objectives of the 1991 research program in Cape Verde with *B. bassiana* were to conduct host range and strain improvement studies, to evaluate and refine new formulations, to adapt formulations to application equipment commonly available in African countries, to assess storage and field stability under African conditions, and to further evaluate the efficacy of *B. bassiana* against African grasshoppers, principally *O. senegalensis*, which is one of the most economically damaging species in Africa. These activities are described below.

HOST RANGE AND STRAIN IMPROVEMENT

One critical task of the 1991 *B. bassiana* research program was to carry out host range and strain improvement studies. Major goals of these studies were to evaluate the range of infectivity within different acridid species and to attempt to obtain reisolates of the Mycotech strain that were more virulent to African species. This research was conducted in cooperation with Dr. Dan Johnson and Dr. Mark Goettel of the Agriculture Canada Research Station, Lethbridge, Alberta. Laboratory tests at the Canadian facility involved both North American and African acridid species.

Six reisolates of the original *B. bassiana* strain were prepared from infected African grasshoppers and locusts, including *O. senegalensis* and *Locusta migratoria migratorioides* (African migratory locusts). Standardized spore preparations of the *B. bassiana* reisolates were then compared to the original strain in laboratory bioassays using African migratory locusts and two species of North American grasshoppers, *Melanoplus bivatatis* and *Meianoplus sanguinipes*. Interestingly, the virulence of any given strain was found to be equally effective against the African migratory locust and the North American species. However, several reisolates were found to be more effective than the original strain against both types of acridians. While these reisolates appeared to be equally virulent, one exhibited significantly greater spore productivity than the others. This latter strain, designated Bb GHA 1991, was used for all 1991 field trials.

Subsequent laboratory bioassays conducted in Cape Verde with the new reisolate against *O. senegalensis* demonstrated that high mortality levels could be achieved at spore dose rates significantly lower than those used in the North American tests. These results indicate the need for further research to determine

the most economical dose rates. In addition, further research is needed to assess potential host range differences. However, project researchers now believe that host range differences are probably insignificant at economical field application rates.

SPORE PRODUCTION

All *B. bassiana* spores used in the 1991 research program were produced by Mycotech at its facilities in Butte, Montana, using proprietary solid substrate culture techniques. Spores were recovered as a dry powder mixed with starch. This powder is stable and can be formulated using a variety of carriers.

For the 1991 trials, both in North American and Cape Verde, the Bb GHA 1991 isolate was grown in a series of bench and pilot scale cultures with dry weight substrate capacities of 1.5 kg, 3 kg, 6 kg, and 20 kg. Spore concentrations ranged from 5.5×10^{10} to 1.2×10^{11} viable spores per gram of dry powder, with a final blended concentration of 7.2×10^{10} spores per gram. Scale-up to larger capacity culture systems has been successful. A prototype commercial system, with a capacity to produce spores for approximately 3,200 hectares per batch (at dose rates used in 1991 field trials), has been constructed and will be undergoing operational tests during winter 1991/1992. Technology used to mass produce spores could easily be adapted to Cape Verde or other West African countries.

FORMULATION

The goal of formulation evaluations was to find carriers for the *B. bassiana* spore powder that minimize dust, have a long shelf life, are stable during field application (meaning that they protect spores from ultraviolet light, heat, and moisture), and can be effectively applied using application technology readily available in Africa. During the earlier 1990 trials in Cape Verde, two different formulations had been used with relative success: oil with an emulsifier, and wheat-bran bait.

In 1991, four different formulations were tested: (1) the oil used the previous year without an emulsifier; (2) the same oil with an emulsifier; (3) wheat-bran bait with improved spore adherence (using molasses as a sticker); and (4) a wettable (clay) powder. The wettable powder was developed from a series of experiments that evaluated four different types of clay for uniform spore suspension, settling time in water suspension, droplet formation, and coverage using backpack and Microulva sprayers. Two types of clay were found to have both good suspension characteristics and close association of spores and clay particles in droplets. Spray

tests using high-volume rates (20 liters/hectare) applied with a backpack sprayer showed uniform coverage and droplet formation in 10 meters swaths (Figure 1).

FIG. 1 - FORMULATION SPRAY TESTS: BACKPACK SPRAYER.

Each of the carriers tested in 1991 has certain desirable characteristics. For example, *B. bassiana* spores are very stable when suspended in appropriate oils. In addition, oil suspensions can be applied using unmodified pesticide spray equipment. Finally, oil carriers ensure good adherence of spores to insects and provide good protection from UV light. A drawback of oil carriers is their relative expense. One way to get around this problem is to add an emulsifier, which allows the oil formulation to be diluted with water. Wettable powders, which consist of certain types of clay, are also very stable when dry. This type of carrier enables spores to be mixed with available water immediately before use, then sprayed using unmodified equipment. Clay promotes uniform water droplets with roughly equal amounts of spores, giving good coverage. Because water is inexpensive, high-volume application rates are feasible. Clay particles also provide some shading, which helps protect against UV light and heat. Disadvantages of wettable powders are the relatively short life of spores when wet and the fact that water suspensions are not as effective as oil in promoting contact and adherence of spores to the insect cuticle. Wheat-bran bait, in which spores are stuck to bran using a sticking agent, is inexpensive and can be applied with several different types of equipment, ranging

from hand-powered spreaders to aerial applicators. A major drawback is its bulk. In short, the formulations tested in 1991 each have distinctive advantages and disadvantages. Together, they provide a range of carrier options that enable *B. bassiana* to be adapted to different pest control situations.

All four formulations tested in 1991 were evaluated by means of storage stability tests, laboratory bioassays, cage trials (which also assessed field viability), and effectiveness in field application. Three different types of application equipment were used in these evaluations: Microulva sprayers, motorized backpack sprayers, and hand-operated spreaders. Cage and field tests using oil formulations involved dosages of approximately 2.5×10^{13} spores per 5 liters oil/hectare, applied with a Microulva sprayer. The wettable powder formulations involved dosages of around 2.5×10^{13} spores in 500 grams of clay suspended in 20 liters of water/hectare for backpack sprayers, and 5 liters of water/hectare for Microulva sprayers. Wheat bran was tested at rates equivalent to 2.5×10^{13} spores on 5 kg wheat bran per hectare. Bran was applied using hand-operated spreaders. The results of these evaluations are described in the following sections.

STABILITY STUDIES

B. bassiana spores, like all fungal spores, are vulnerable to excessive heat and/or moisture. One of the major goals of the 1991 research program in Cape Verde was to evaluate the stability of this fungus under storage and field conditions that could reasonably be expected in West Africa.

To assess the stability of the Bb GHA 1991 strain, tests were conducted in Cape Verde to evaluate the combined effects of temperature and humidity on the unformulated spore powder, the oil formulations, and the wettable powder formulation. Parallel tests in Montana evaluated the combined effects of high temperature and aridity. The Cape Verde tests measured the stability of each of the formulations at 4 different relative humidities (0%, 45%, 75%, and near 100%) and 3 different temperatures (10°, 31°, and 40° C).

Spore preparations were put in open petri dishes. These were placed in plastic containers on screens above agents designed to maintain varying relative humidities (RH), after which the containers were sealed. RH 0% was maintained with a desiccant, RH 45% and 75% were maintained with saturated salt solutions, and near 100% RH was maintained with water. The plastic containers used are shown in Figure 2.

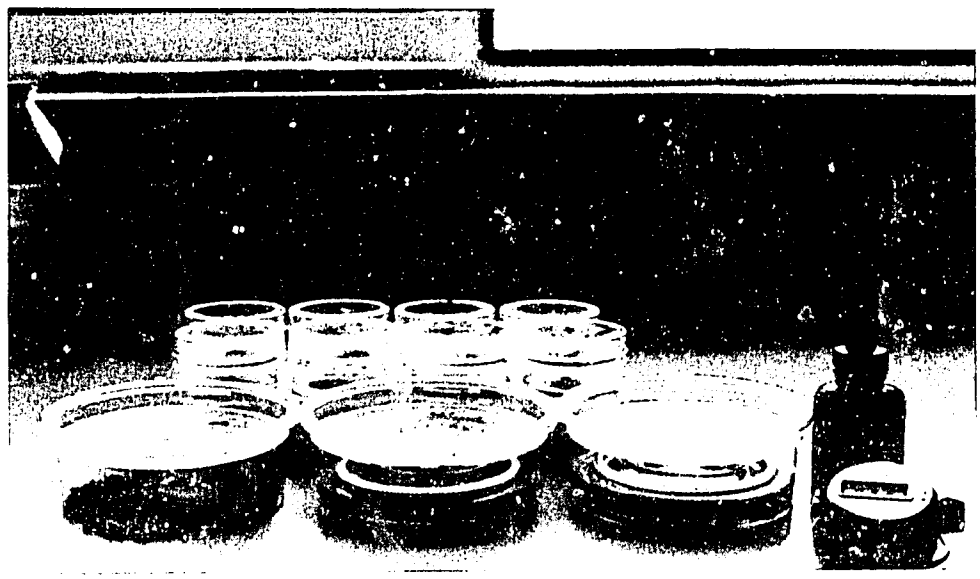


FIG. 2 - LABORATORY STABILITY STUDY. FORMULATIONS IN OPEN PETRI DISHES WERE PLACED IN CONTAINERS ON SCREENS ABOVE DESICCANT, SALT SOLUTIONS, OR WATER AND THE CONTAINERS WERE SEALED.

After preparation, the plastic containers were incubated at 10° and 31° C, then sampled and examined over time for percentages of viable spores. Viable spores were determined by microscope germination assays. At 10° C, all spore preparations or formulations were stable (maintained peak viability) at 0% RH, 45% RH, and 75% RH for at least 39 days. At 100% RH, all preparations maintained greater than 80% viability for at least 21 days, while the wettable powder formulation still had 84% viability at 39 days.

At 31° C and both 0% and 45% RH, all preparations maintained greater than 80% viability for at least 39 days. At 75% RH, all preparations were stable for at least 21 days. Unformulated, exposed spore powder proved to be relatively unstable at both 75% and 100% RH, losing its viability after only four days.

Stability tests in Montana in 1991 evaluated the combined effects of high temperature and aridity. Under the relatively arid conditions prevailing in Butte, Montana, the stability of spores in both unformulated spore powder and oil formulations in closed plastic bottles was tested at 40° C. After 18 days, the dry spore powder still had 58% spore viability and the oil formulations had 80% viability (Figure 3).

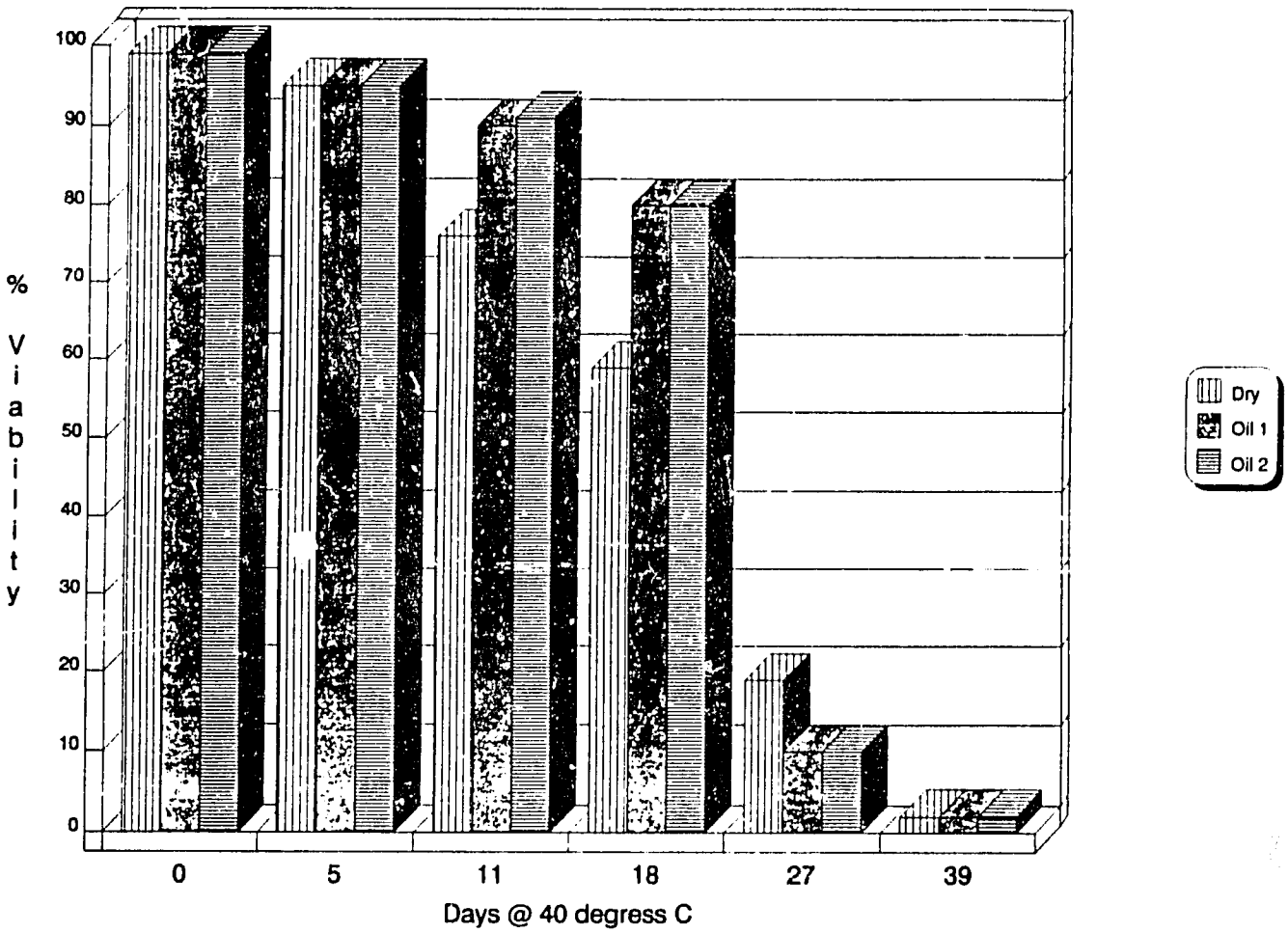


FIG. 3 - RESULTS OF HIGH TEMPERATURE STABILITY STUDIES

The stability studies undertaken in 1991 demonstrated that formulation carriers both enhance storage stability and help protect against the detrimental affects of high temperatures and high humidity. Results also showed that although prolonged exposure to temperatures above 40° C and high humidity should be avoided, *B. bassiana* is stable enough to be effectively integrated into typical product storage and distribution systems prevailing in West Africa.

LABORATORY BIOASSAYS

Laboratory bioassays were conducted in Cape Verde in 1991 to assess the efficacy of the new strain of *B. bassiana* against *O. senegalensis*, as well as to evaluate improved formulation and application methods. For these bioassays, *O. senegalensis* grasshoppers were field collected and held for at least 24 hours prior to testing to minimize bias from mortality due to handling. Bioassays involved two basic procedures: (1) single droplets of an oil formulation measuring 0.5 microliters were applied topically to the wing pads of individual grasshoppers; and (2) a wettable powder formulation was applied to 1 cm discs cut from fresh corn leaves, these discs were allowed to dry, then they were given to individual grasshoppers in small rearing cups. (Rearing cups used in the bioassays in Cape Verde are shown in Figure 4).

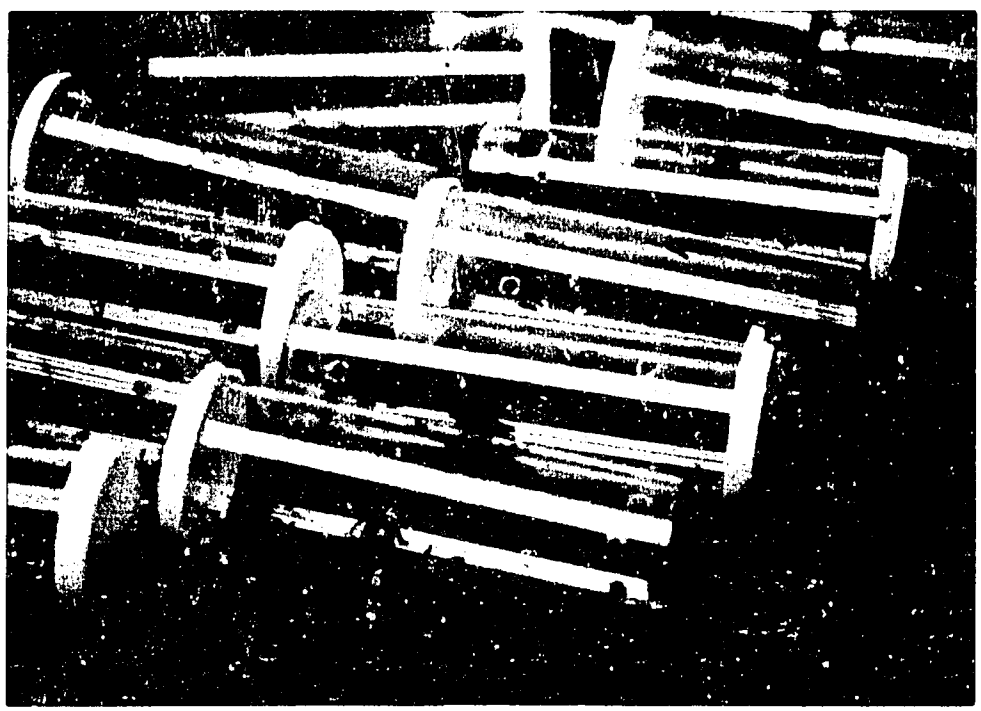


FIG. 4 - REARING CUPS CONTAINING INDIVIDUAL GRASSHOPPERS HELD FOR MORTALITY OBSERVATION. FOOD (FRESH GRASS) WAS CHANGED DAILY.

For each formulation (oil and wettable powder), the following four dosage rates of *B. bassiana* were tested: $1x10^3$, $1x10^4$, $5x10^4$, and $1x10^5$ spores per insect. Twenty grasshoppers were treated at each dose rate, then reared individually in rearing cups and observed daily for mortality. Four replications of each experiment

were conducted. Control groups for topically applied oil formulations included both untreated grasshoppers and grasshoppers treated topically with oil droplets without spores. Control groups for the wettable powder formulation were given untreated corn discs.

As Figure 5 demonstrates, greater than 90% mortality was observed at all dose rates with the topically applied oil formulation. With the highest dose rate, (a dosage that is economically feasible), 100% mortality was achieved in 5 days. The LD_{50} (lethal dose for 50% of the population) for the oil formulation was found to be approximately 1,000 spores per grasshopper. This indicates exceptionally high virulence. The LT_{50} (lethal time for 50% of the population) was 4 to 5 days at 1,000 spores per grasshopper. With the wettable powder formulation applied to corn discs, mortality reached 88% at the highest dose rate. The LD_{50} was between $5x10^4$ and $1x10^5$ with an LT_{50} of 5-6 days at $1x10^5$ spores per insect.

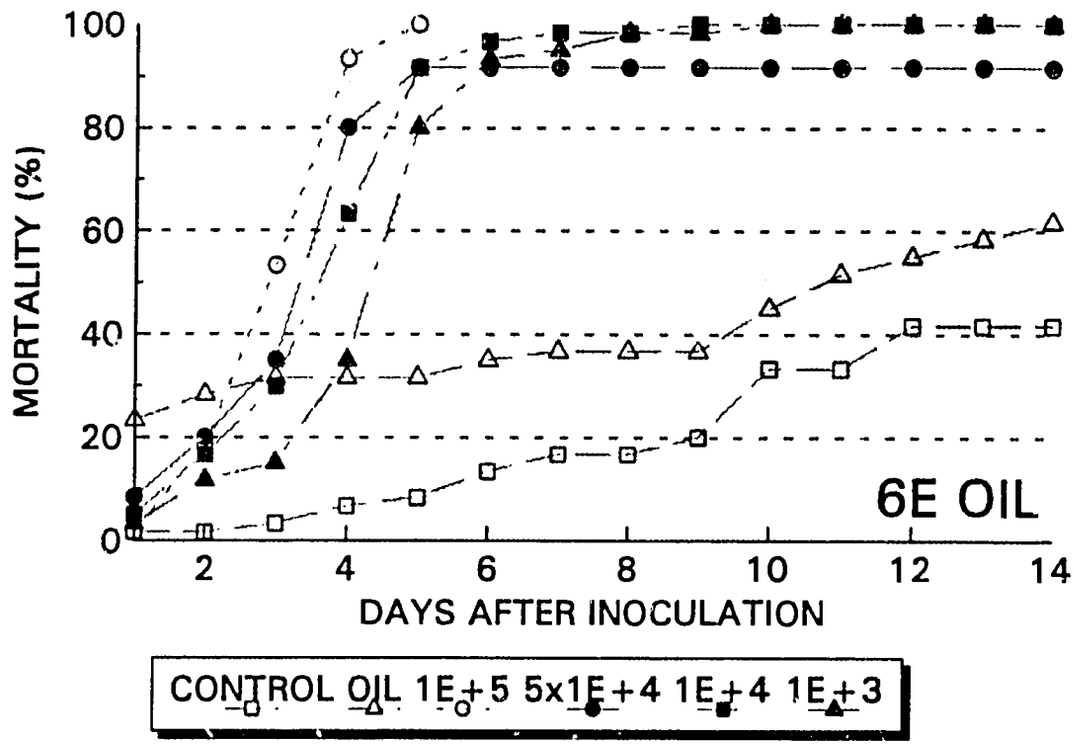
The Cape Verde bioassays demonstrate: (1) that topically applied oil formulations of *B. bassiana* are highly lethal at economically feasible dosage rates; and (2) that grasshoppers given sufficiently high levels of *B. bassiana* spores on vegetation also experience high mortality. These assays suggest that oil sprays may prove to be the most efficacious way to apply *B. bassiana* spores. Indeed, as Figure 5 shows, the control group of grasshoppers treated with oil droplets without spores experienced significantly higher mortality than the untreated control group.

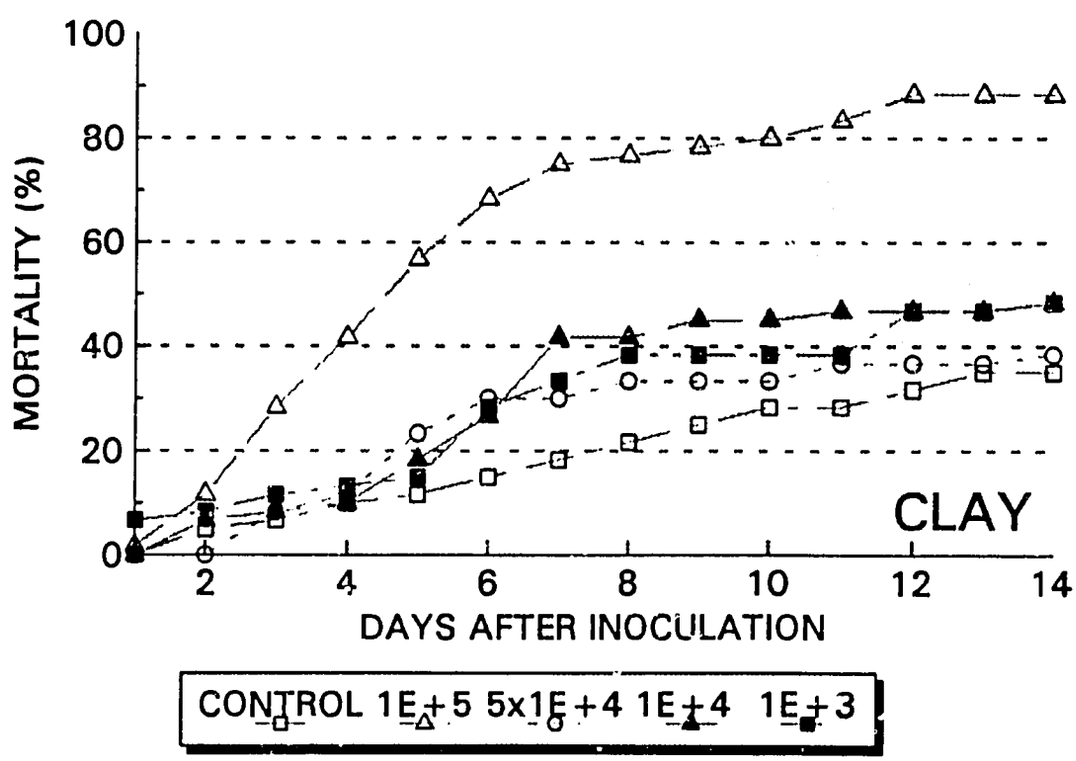
Follow-up bioassay research with *B. bassiana* is needed, including assays with wettable powder formulations topically applied to grasshoppers, and assays with oil formulations sprayed on corn discs. In addition, project researchers now believe that infection from the treated corn discs results not so much from actual ingestion as from physical contact with viable spores on the vegetation, which then penetrate from the outside, possibly through the mouth parts. More research is needed to confirm this theory, which will have major implications for future formulation development for fungal bio-insecticides.

CAGE TRIALS

Cage trials were conducted in Cape Verde in 1991 to evaluate the infectivity of *B. bassiana* spores sprayed on vegetation under field conditions. These trials were designed to answer a key biocontrol question: if grasshoppers are missed by spray droplets of the bio-insecticide at the time of application, to what degree will they become infected through secondary contact with sprayed vegetation? More specifically, research goals were to compare the relative infectivity of different formulations sprayed on vegetation and to determine how long infective levels of spores remained on vegetation following exposure to African weather conditions.

FIGURE 5. Bioassay of Beauveria bassiana in oil or clay formulations against third and fourth instar nymphs of Oedaleus senegalensis in Cape Verde.





Each formulation was applied to 20 m^2 plots of native vegetation at a rate of 2.5×10^{13} spores per 5 liters liquid or 5 kg bran per hectare. Liquid formulations were applied using Microulva sprayers and the bran bait was applied with hand-powered spreaders. Next, field-collected *O. senegalensis* grasshoppers were placed on the treated plots in 1 m^2 screen cages at 1 hour, 24 hours, and 72 hours after application. Three replicate cages were used at each time interval. Grasshoppers placed in the cages were held on the treated vegetation for 24 hours, after which 20 randomly selected grasshoppers were removed from each cage and held in individual rearing cups in the lab for mortality observation. During the observation period, the hoppers were fed fresh, unsprayed vegetation.

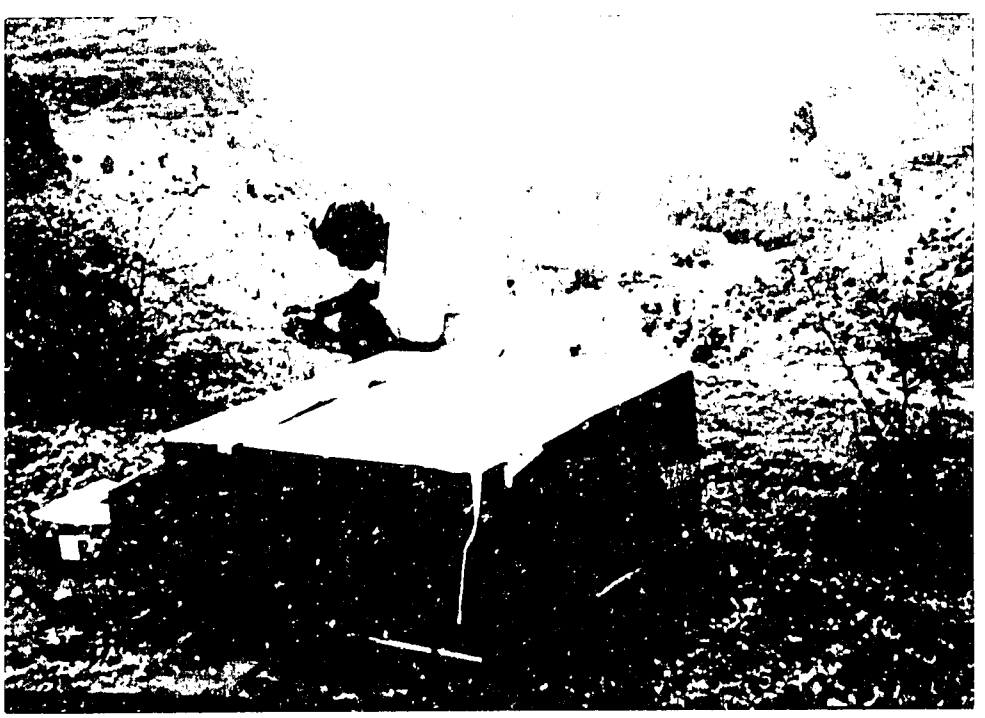
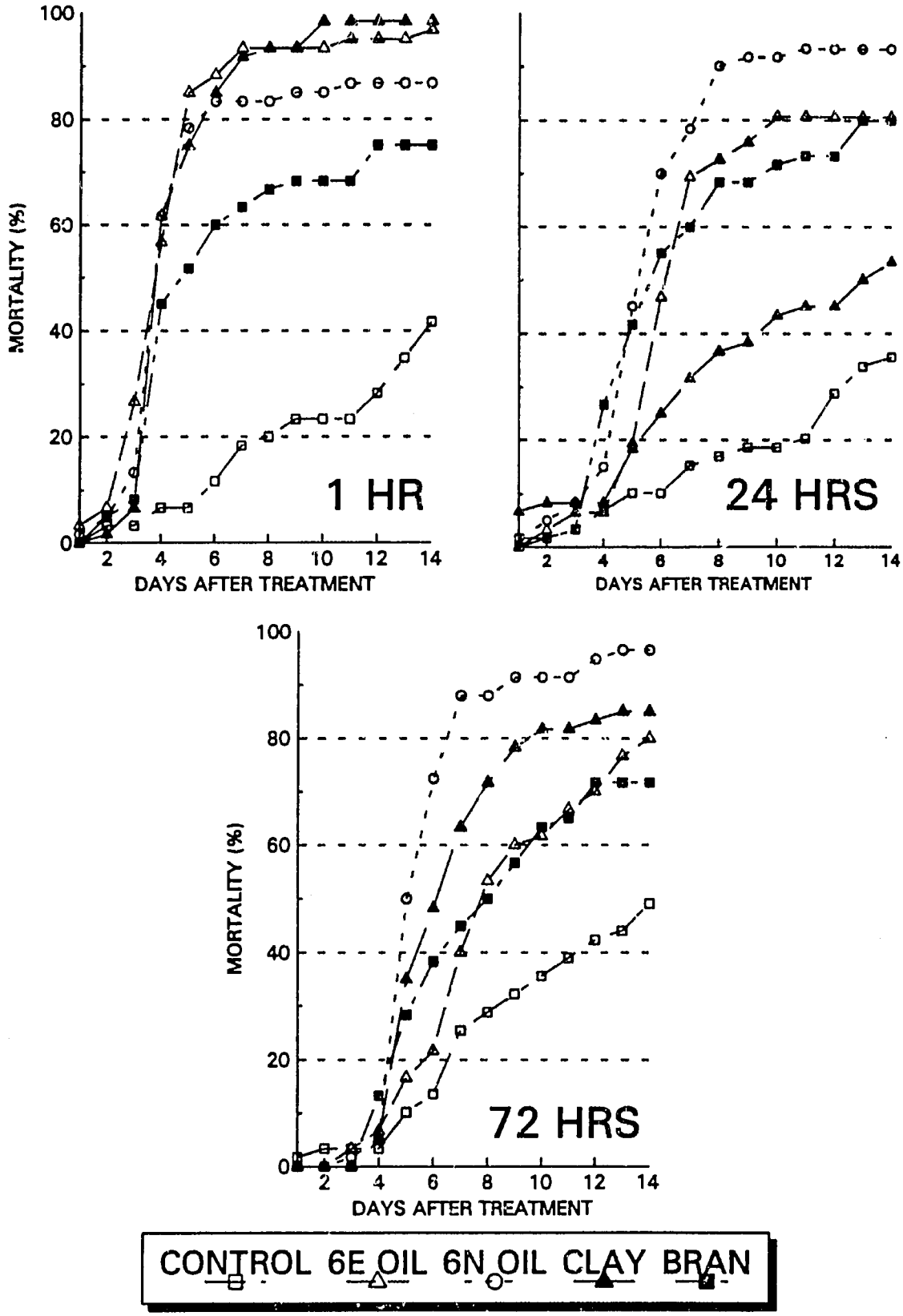


FIG. 6 - VEGETATION TREATMENT. SCREEN CAGES MEASURING 1 SQUARE METER WERE USED TO CONTAIN *O. Senegalensis* GRASSHOPPERS FOR 24 HOURS ON VEGETATION TREATED WITH *B. bassiana.*

Figure 7 presents the results from the field cage trials. With exposure to treated vegetation 1 hour after application, all liquid formulations achieved at least 80% mortality in 5 to 6 days, with the wettable powder and oil with emulsifier formulations eventually achieving near 100% mortality. No significant differences were observed between the oil and wettable powder (clay) formulations. By contrast, bran bait resulted in lower mortality rates (approximately 60% mortality at 6 days), but these rates were still much higher than mortality rates in the control groups.

FIGURE 7. Cumulative mortality among Oedaleus senegalensis placed on vegetation treated with Beauveria bassiana in oil, clay or wheat bran.



Results from the 1-hour trials are important because they suggest that most of the grasshoppers in an area sprayed with *B. bassiana* will be killed even if they are not directly hit by the spray since they are likely to encounter treated vegetation within an hour of application.

Overall, the field cage trials showed that an infective level of spores remained on the treated vegetation for at least 3 days after application. With the oil and wettable powder formulations, mortalities exceeding 80% were obtained following exposure to sprayed vegetation 3 days after application. Weather conditions during these trials were hot and sunny. These results showed both that secondary contact with spores on sprayed vegetation was an important source of infection, and that formulations provided sufficient protection to maintain an infective level of spores for at least three days, despite exposure to tropical sunlight, heat, and humidity. Very similar results were obtained from vegetation experiments conducted in North America. These results show that grasshoppers that are missed by spray, hatch later, or migrate into treated areas can be effectively killed. Project researchers did not assess spore viability after the 72-96 hour period because they did not expect the *B. bassiana* spores to remain viable beyond this point. The surprising longevity of the spores points to the need for additional studies to determine how long an infective level remains on vegetation.

FIELD TRIALS

Field trials in Cape Verde in 1991 involved testing different formulations of *B. bassiana* against grasshoppers in open-air $50m^2$ enclosures. These enclosures, which measured 5m x 10m, were constructed of stakes and cloth mesh 0.5m high (see Figure 8). They were intended to limit migration of grasshoppers into or out of the test area but otherwise to simulate normal field conditions, including exposure of spores to tropical sunlight, heat, and humidity. The purpose of these trials was to test the viability of *B. bassiana* under field conditions.

Prior to spraying, grasshopper populations in the enclosures were supplemented by field-collected grasshoppers from the surrounding area to produce a final test population density of around 25 grasshoppers per square meter. Field-collected grasshoppers were held for 24 hours prior to use to control for mortality from handling, with only healthy individuals selected for the tests. Four formulations were used in the field trials: (1) oil (6N); (2) oil with an emulsifier (6E); (3) wettable powder (clay); and bran bait. Each formulation was applied to four different $50m^2$ plots at a rate equivalent to $2.5x10^{13}$ spores per 5 liters of liquid or 5 kg wheat bran per hectare. Microulva sprayers were used for the liquid formulations, and a hand-powered spreader was used for the bran bait. Four untreated plots served as

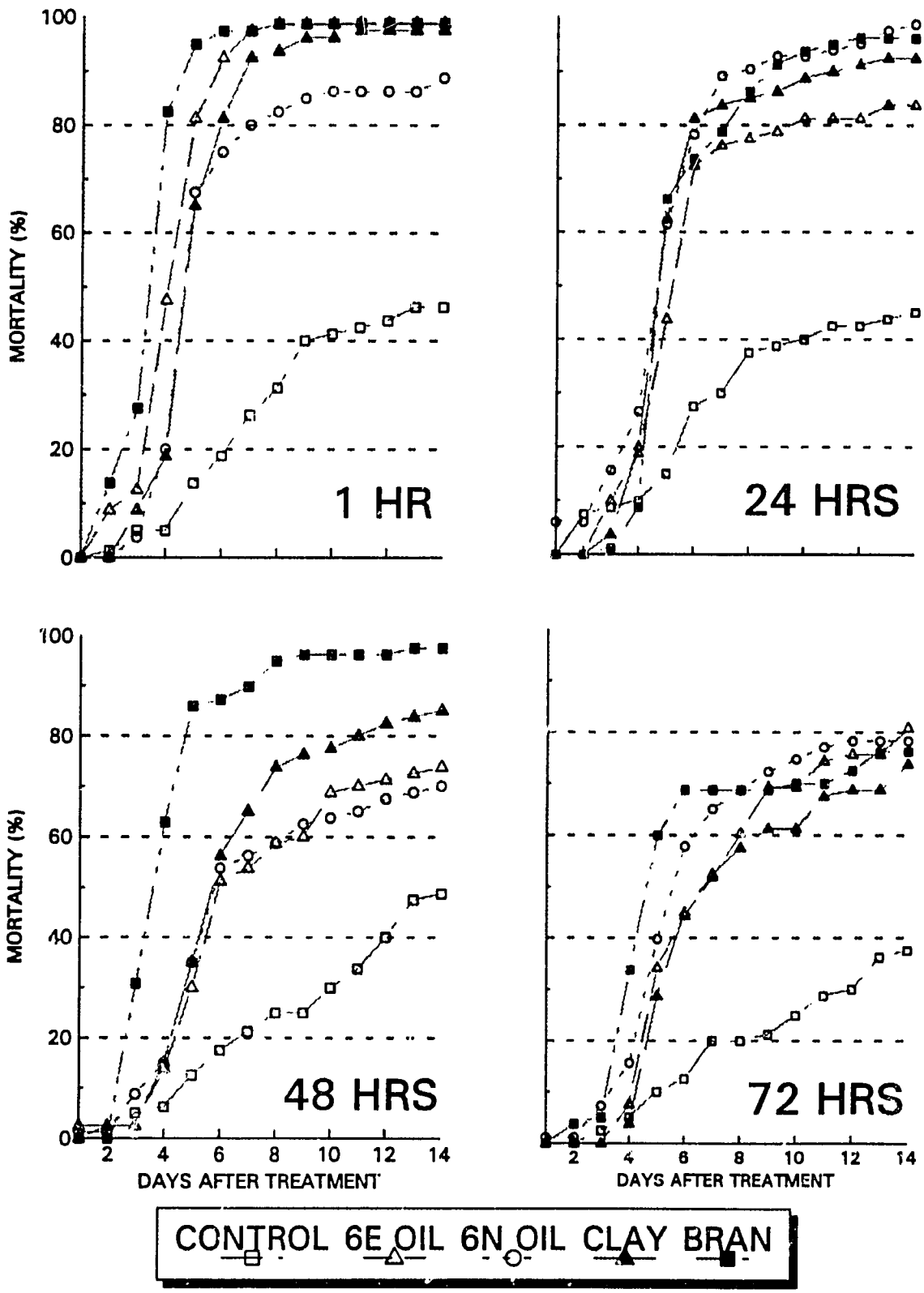
controls. In all, the 1991 Cape Verde field trials involved 20 different $50m^2$ enclosures.

FIGURE 8 - FIELD TRIAL. FIFTY SQUARE METER ENCLOSURES WERE USED TO TEST FORMULATIONS UNDER FIELD CONDITIONS. ENCLOSURE BEING TREATED WITH *B. bassiana* WHEAT BRAN BAIT.

Following application of the various formulations of *B. bassiana*, infection was evaluated by randomly gathering 20 *O. senegalensis* grasshoppers from each field-trial plot at the following post-treatment periods: 1 hour, 24 hours, 48 hours, and 72 hours after application. Grasshoppers collected were held for observation in individual rearing cups. Figure 9 presents the mortality results observed in the sample grasshopper populations.

As Figure 9 demonstrates, all four formulations rapidly achieved high levels of mortality in the sample populations of *O. senegalensis* collected 1 hour after application. By the second day following exposure, grasshoppers in the treated plots were visibly sick and exhibited limited movement and feeding. Significant mortality levels were observed in these sample populations beginning 3 to 4 days after exposure.

FIGURE 9. Cumulative mortality among Oedaleus senegalensis following treatment of field enclosures with Beauveria bassiana in oil, clay or wheat bran.



Bran bait, the formulation with the greatest observed potency in the sample populations gathered 1 hour after treatment, achieved around 95% mortality in 5 days and near 100% mortality in 8 days. The wettable powder (clay) and oil-with-emulsifier (6E) formulations, while slower acting, achieved comparable levels of mortality. The plain oil formulation (6N) was only slightly less effective. Samples collected at 24, 48, and 72 hours after application revealed similar but gradually lower mortality levels. The gradual reduction in grasshopper mortality levels over time is due to several key factors, including prior mortality in the test population, new hatching, and migration into the plots. In all, the 1991 field trials in Cape Verde demonstrated that *B. bassiana* was very effective in causing rapid and high levels of mortality in populations of *O. senegalensis* grasshoppers under field conditions in Africa.

CONCLUSIONS

Research funded by A.I.D.'s Africa Bureau to develop the fungus *B. bassiana* for grasshopper and locust control in Africa achieved major advances in 1991. Primary research objectives were to evaluate new formulations of *B. bassiana*, to adapt formulations to application equipment commonly used in Africa, to assess storage and field stability under African conditions, and to evaluate the efficacy of a new strain of *B. bassiana* against African grasshoppers, principally *Oedaleus senegalensis*, one of the most economically damaging species in Africa. These objectives were accomplished with a high level of success.

Field trials in Cape Verde evaluated the efficacy of 4 different formulations of *B. bassiana*. These were applied with available hand-held application equipment. The most successful formulations caused reduced feeding and mobility by the second day and achieved nearly 100% mortality within a week. These are by far the best results that have yet been obtained in field trials with natural entomopathogens against grasshoppers in Africa. Mortality levels with *B. bassiana* compare favorably with those achieved with chemical pesticides, without any of the associated environmental and public health risks. Results in Cape Verde were very similar to those achieved by project researchers in three separate field trials conducted in the United States and Canada during 1991. The *B. bassiana* isolate in question has proven to be highly virulent to all 14 grasshopper and locust species tested to date, including *O. senegalensis* and *L. m. migratorioides.* In short, the 1991 trials in Cape Verde suggest that *B. bassiana* can be developed into an effective and environmentally friendly bio-insecticide for grasshopper and locust control in Africa.

All formulations of *B. bassiana* tested in 1991 are economically feasible and cost competitive with chemical pesticides presently used for grasshopper and locust control. Research in 1991 demonstrated that *B. bassiana* spores can be

successfully formulated with a wide variety of carriers and applied using available equipment, without the need for modification. Stability studies showed that formulations of *B. bassiana* are very stable under normal storage and distribution conditions in Africa. Field results demonstrated that spores on sprayed vegetation were an important source of infection and that formulations provided sufficient protection to maintain an infective level following at least 3 days of exposure to tropical sunlight, heat, and humidity. The 1991 results in Cape Verde suggest that project researchers are on the threshold of a major breakthrough in biocontrol. These results warrant further applied and implementation research to develop *B. bassiana* for grasshopper and locust control in Africa.

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